

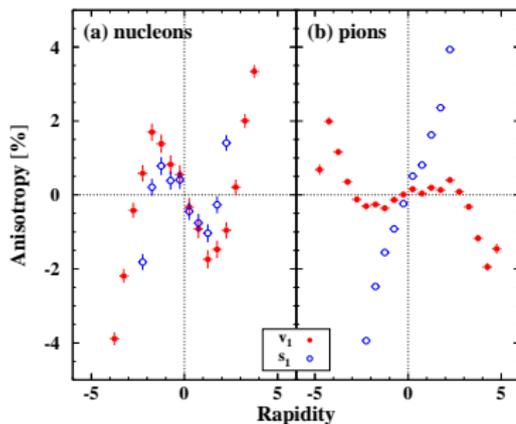
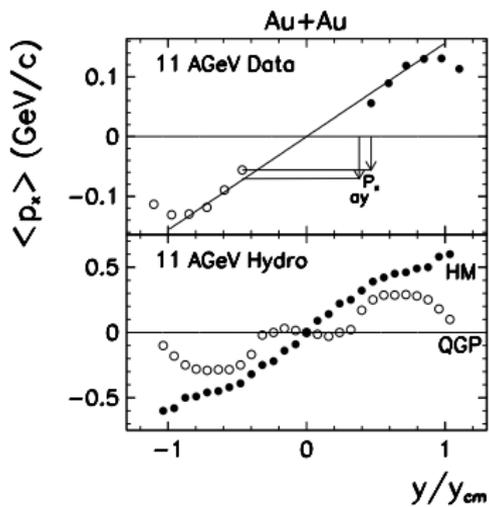
# Directed flow in ultrarelativistic heavy-ion collisions

Piotr Bożek

IFJ PAN Kraków

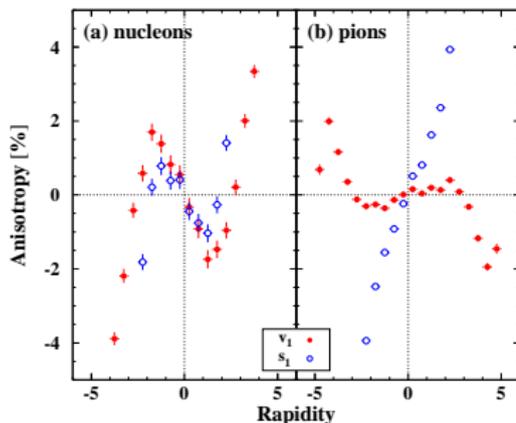
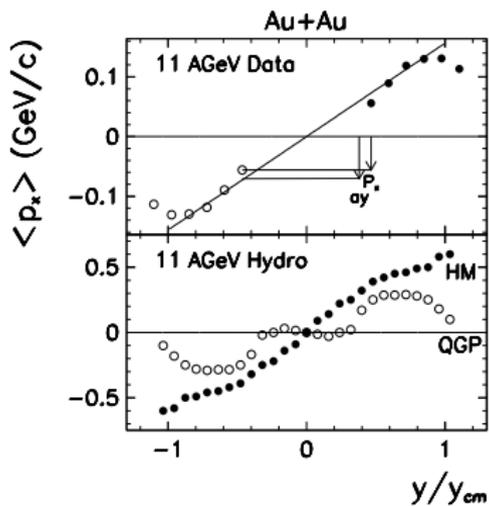
07.06.2010





Velocity gradients (Snellings et al.)

EOS (Csernai, Roehrich)

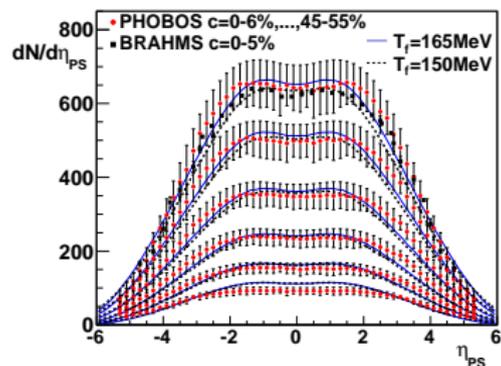


Velocity gradients (Snellings et al.)

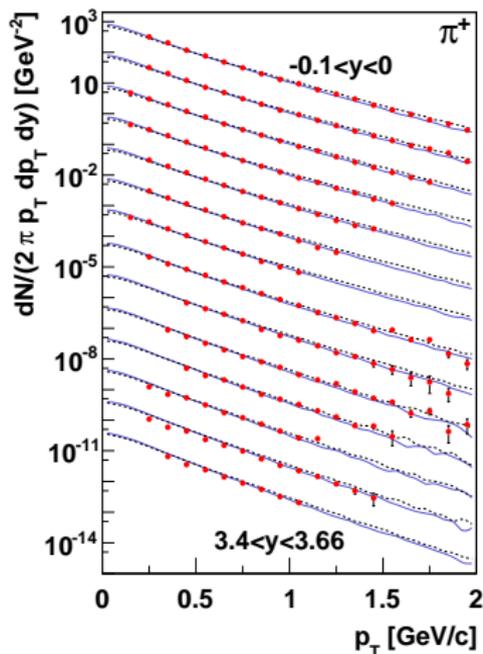
EOS (Csernai, Roehrich)

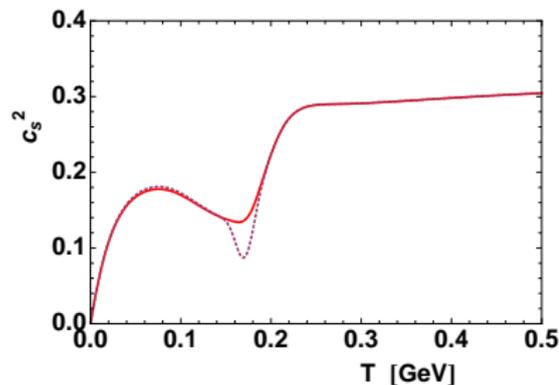
Reality check at 200GeV:

Models do not describe data - very sensitive observable

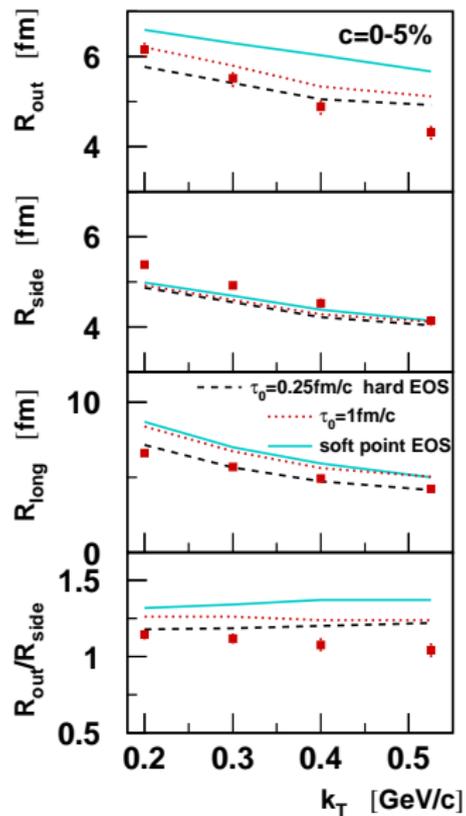


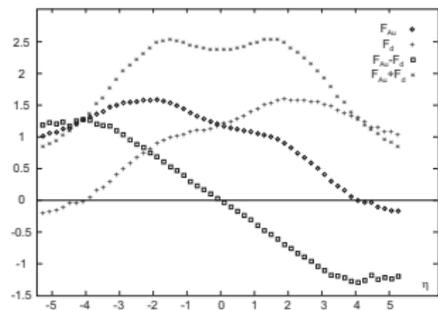
(PB, Wyskiel)



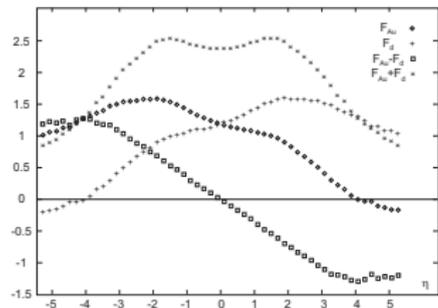


“Modern” lattice based EOS  
(Chojnacki, Florkowski)

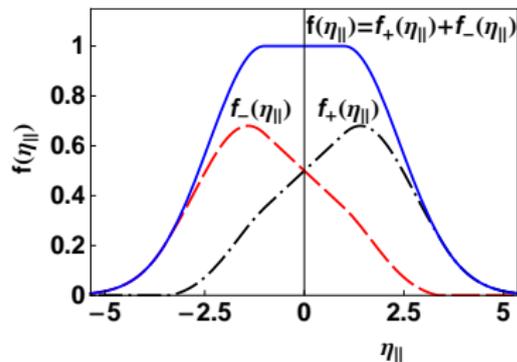


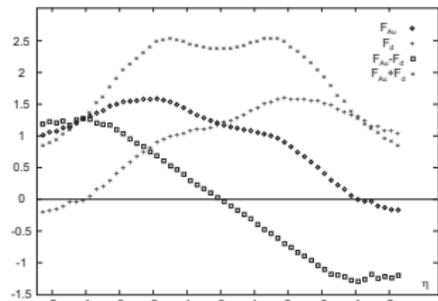


Asymmetric emission  
(Białas, Czyż)

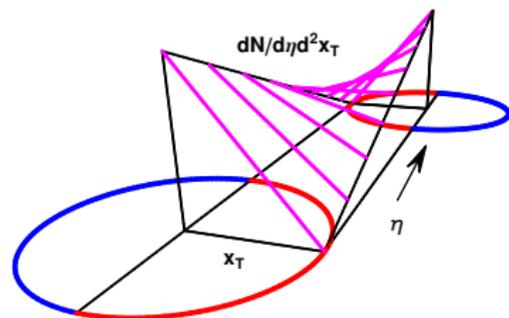
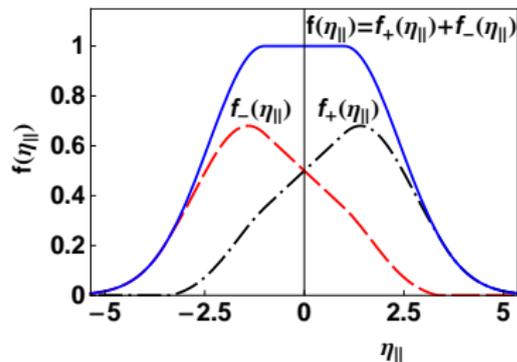


Asymmetric emission  
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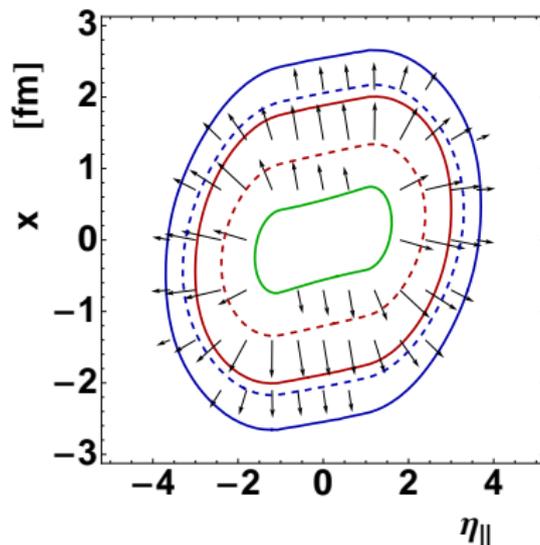




Asymmetric emission  
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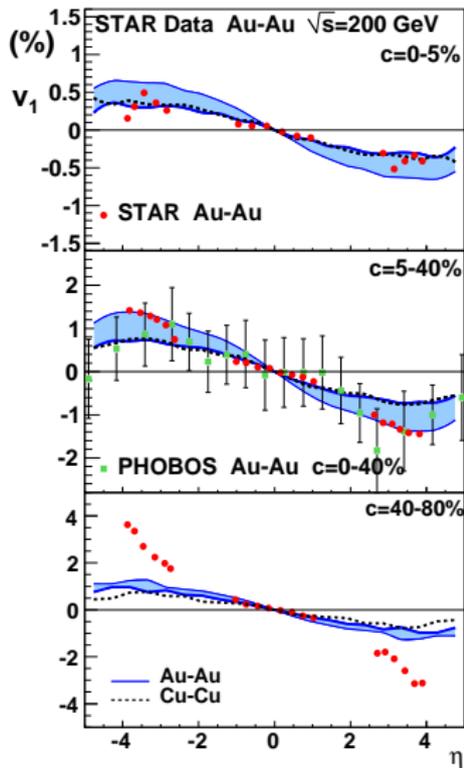


bremsstrahlung (Adil Gyulassy)



PB, Wyskiel

tilted source  $\rightarrow$  transverse pressure + longitudinal pressure  
Glauber Model



- ▶ Anti-flow explained!
- ▶ System size dependence
- ▶ Consistent with asymmetric emission

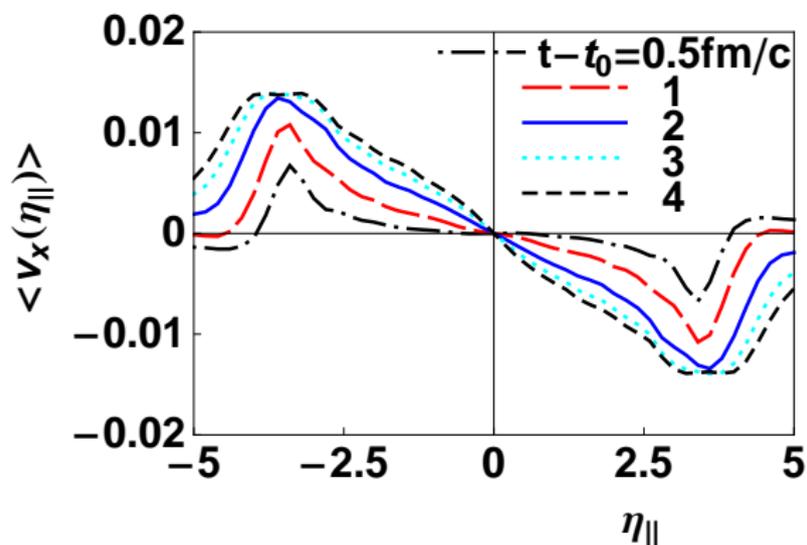
# Yet Another Obscure Boring Observable?

# Yet Another Obscure Boring Observable?

**NO**

## Great Unique Observable For Early Longitudinal Pressure

# Early collectivity



$v_1$  develops before  $v_2$

CGC

$$T^{\mu\nu} = \begin{pmatrix} \epsilon & 0 & 0 & 0 \\ 0 & \epsilon & 0 & 0 \\ 0 & 0 & \epsilon & 0 \\ 0 & 0 & 0 & -\epsilon \end{pmatrix}$$

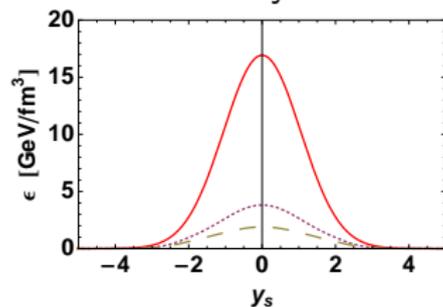
Nonequilibrium, viscosity

$$T^{\mu\nu} = \begin{pmatrix} \epsilon & 0 & 0 & 0 \\ 0 & p + \pi/2 & 0 & 0 \\ 0 & 0 & p + \pi/2 & 0 \\ 0 & 0 & 0 & p - \pi \end{pmatrix}$$

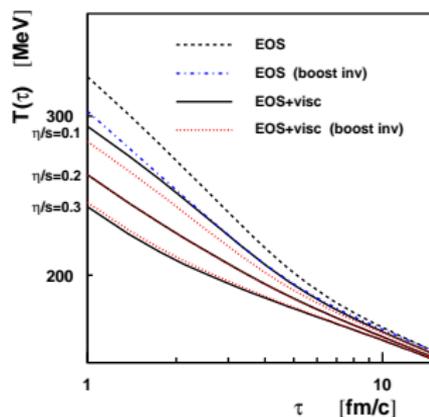
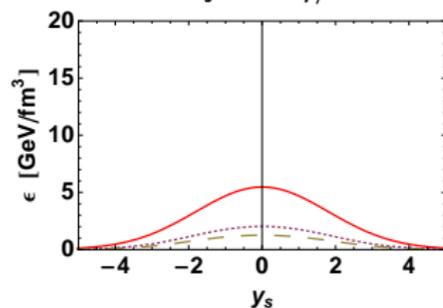
**What signatures of isotropization?**

# Longitudinal expansion - cooling

## Ideal hydro

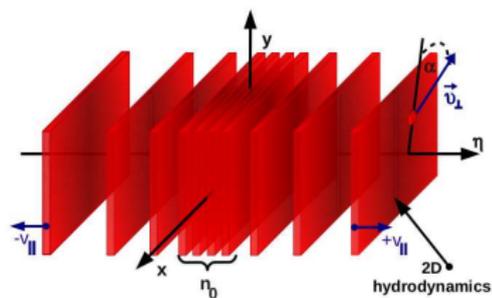


## Viscous hydro $\eta/s = 0.2$



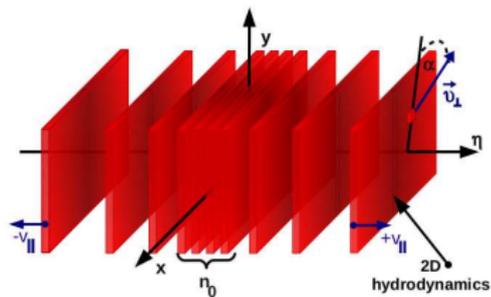
Cannot be observed in final distributions!

# Transverse expansion scenarios

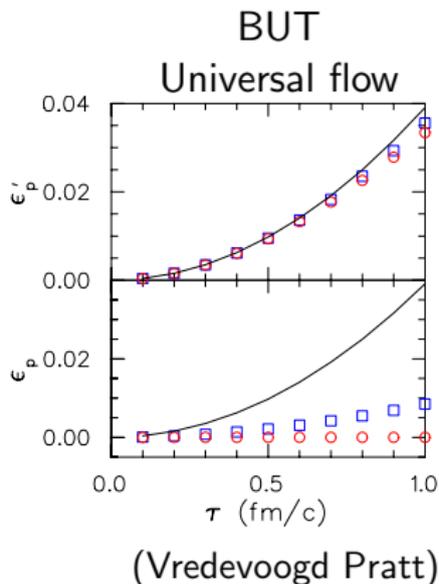


- ▶ 2D hydro
- ▶ Early dissipation
- ▶ Shear viscosity
- ▶ Free streaming
- ▶ Color fields

# Transverse expansion scenarios



- ▶ 2D hydro
- ▶ Early dissipation
- ▶ Shear viscosity
- ▶ Free streaming
- ▶ Color fields

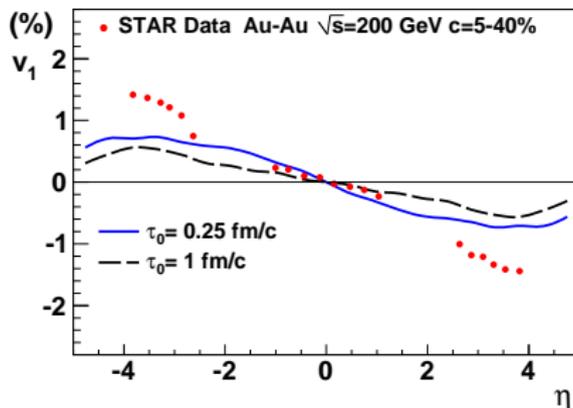


Small effect of early transverse pressure

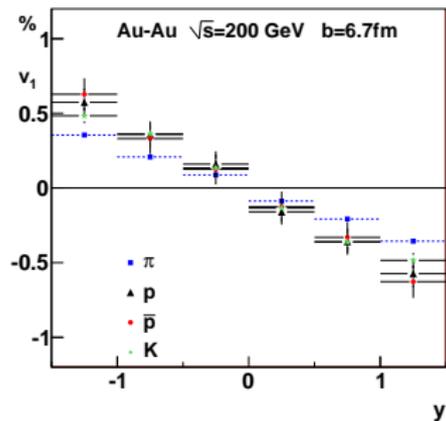
**Answer**

# Answer

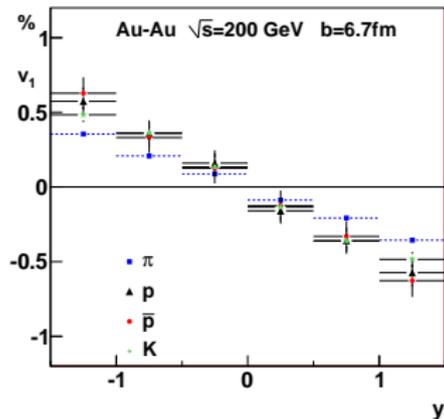
Transverse + Longitudinal Expansion = Directed Flow



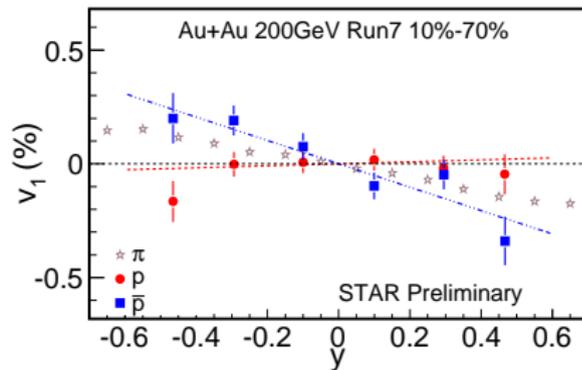
longitudinal pressure appears before 1fm/c  
fast isotropisation



Hydro : mass scaling

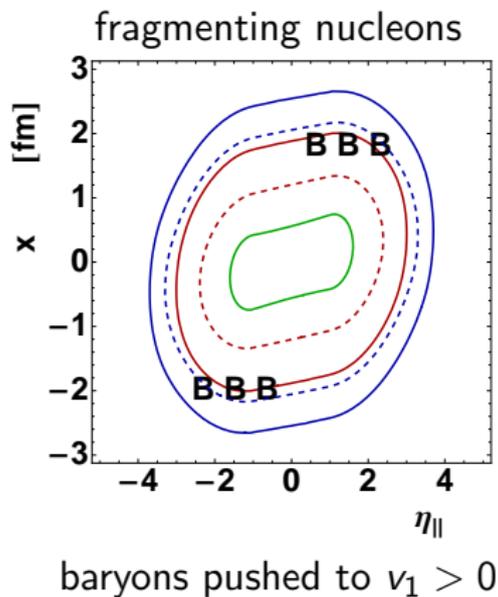


Hydro : mass scaling

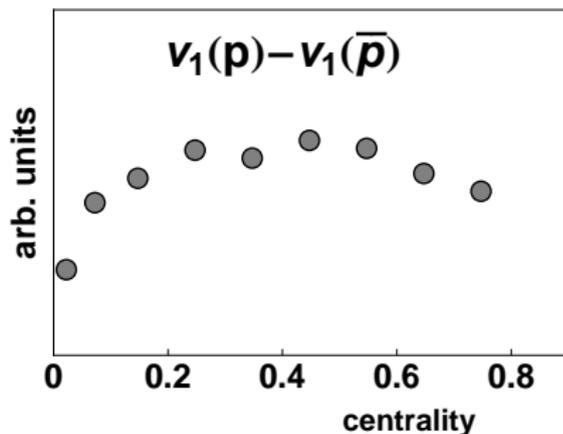


Zero baryon flow! (STAR)

# Baryon asymmetry!



$$\Delta v_1 \propto \frac{\mu}{T} \frac{N_+ - N_-}{N_+ + N_-}$$



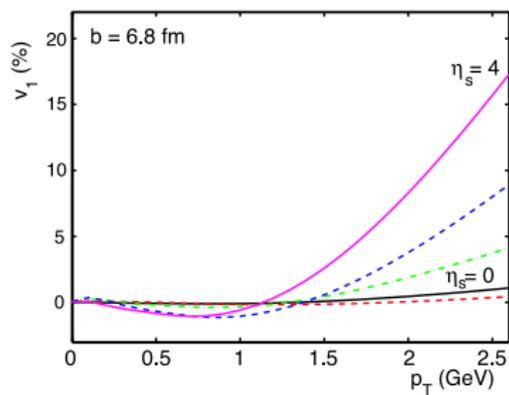
## **Directed Flow** **The Observable of Early Thermalization**

## Directed Flow The Observable of Early Thermalization

1. Directed flow at RHIC  $\leftrightarrow$  **HYDRODYNAMICS**
  - ▶ explains anti-flow
  - ▶ right magnitude
  - ▶ system size scaling
2. Qualitatively explains : PID flow (and  $p_{\perp}$  dependence)

**Longitudinal pressure appears early!**

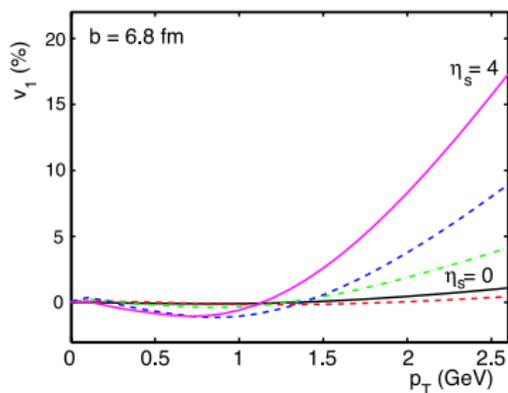
# $p_{\perp}$ dependence



deformed source  
(Kolb Heinz)

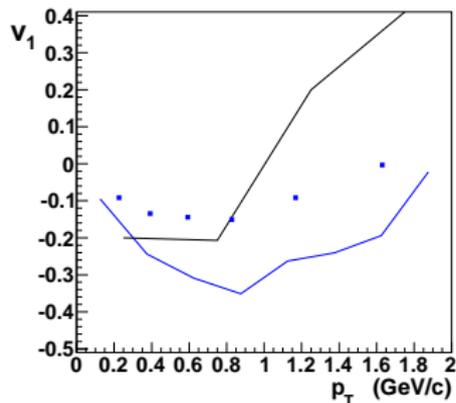
$$\langle p_x \rangle = 0$$

# $p_{\perp}$ dependence



deformed source  
(Kolb Heinz)

$$\langle p_x \rangle = 0$$



3+1D  $\rightarrow$  shift to  $v_1 < 0$